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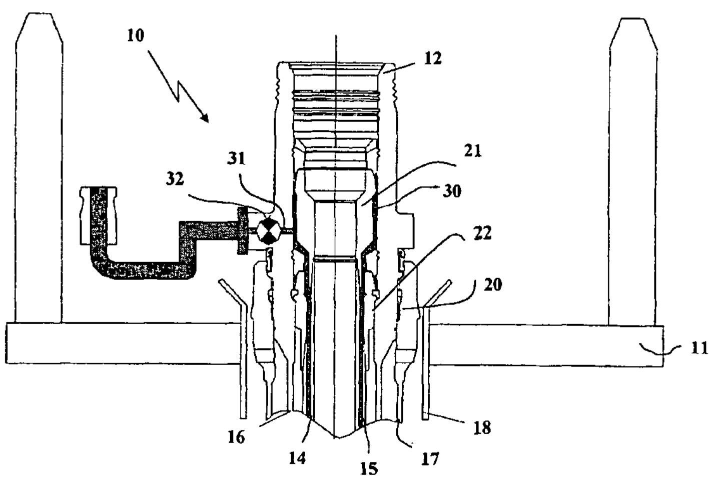
(54) Title: ANNULUS MONITORING SYSTEM



(57) Abstract: Apparatus and a system for accessing one or more of the annuli defined between casing strings in a subsea wellhead that are usually sealed for the production stage of the well. Access to an annulus (30) is made via the wall of the wellhead housing (12) at a location where is communicates with the annulus. The access is a passageway (31) having a first opening in communication with the annulus and a second opening either at the external surface of the wall or at a location on the inner surface of the wall above the casing hangar seal for the inner casing (14), which is not in communication with the annulus apart from the passageway. An isolation valve (32) communicates with the passageway and with apparatus for monitoring or controlling pressure of flow in the annulus. The passageway may be used with an open lower end to the annulus during drilling stages for material transfer and during production stage to monitor/control a sealed annulus.

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ANNULUS MONITORING SYSTEM

This invention relates to subsea wellheads and to casings for such wellheads.

More particularly it concerns providing a way of accessing an annular passageway (or annulus) defined between concentric casings, and to a pressure monitoring and/or control system for the annulus The casings may be part of a series of casing strings. The pressure control may include movement of materials and the access may be used at the drilling or completion stage or during production.

Well casing emerging from subsea deposits of oil and/or gas is required to contain well fluids under high pressures. The well casing may typically be of 10 3/4" OD (approx 273mm) pipe. The well casing is secured to a well casing hanger within the wellhead and coaxial with the well bore. The well casing is surrounded by a further casing, which forms an outer barrier of an annulus formed between the two casings. The further casing may be of 13 3/4" (approx 356mm) OD pipe. This further casing may also be surrounded by other casings. During drilling the casings are open at the top and bottom, but they are generally sealed at various stages prior to production. Access to the innermost annulus is maintained via the top and valves but there is not sufficient space to provide such access to other annuli.

To prevent collapse under subsea pressure the annuli between the successive concentric casings are filled with fluid, which may be for example gas, drilling mud or water. The fluid is generally injected into the annulus via the open annulus access of the top during the completion phase of the well when the casings are sealed. For the avoidance of doubt, in this specification the expression fluid covers any flowable substance which may be gas or liquid, or suspensions or slurry. If leakage from production occurs or there is other ingress of fluid into an annulus there can be a build up of pressure. Presently, if this occurs the casings have to be pulled up, which requires the well to be shut down. It is being found that as drilling goes to deeper formations, the resulting higher temperatures and pressures increases the instances of pressure build up.

There are also other circumstances where the balance of pressures on the casings changes. On the inside there is high pressure from the reservoir and on the outside deep

sea pressure. During the course of production pressure may change, for example reducing pressure due to natural depletion of the reservoir, which may also be accompanied by changing temperatures; in the example just mentioned, a temperature drop. Such pressure changes can result in a differential pressure increase, collapsing or bursting of casings or damage to the formation.

Thus it is desirable at the production stage to be able to monitor pressure within an annulus between concentric casings and/or to be able to bleed, circulate or inject fluids in order to change or restore the annulus pressure to a particular level. It is also desirable to be able to utilise the annuli for movement of material, either as part of drilling, after drilling or during production.

There are also instances where the ability to pressurize an annulus may enable design changes to casing thickness. Also respective concentric annuli may be held at different pressure levels.

According to the invention there is provided a wellhead housing assembly for a subsea wellhead, the assembly comprising a wellhead housing that is adapted to receive a plurality of casing strings therewithin with an annular passage defined between respective adjacent casing strings, and in which the wall of the wellhead housing has a penetration with a first opening on its inner surface in a location that will communicate with one annular passageway formed by a pair of adjacent casing strings, the penetration extending to a second opening on a surface portion of the wellhead housing wall that will not be in communication with any annular passageway between casing strings.

The invention also provides a pressure monitoring/control system for a subsea wellhead arrangement including an inner pipe surrounded by an outer pipe and defining an annular passage therewith, the inner and outer pipes being adapted to withstand internal and external pressure and the annular passage being filled with fluid to prevent compression, characterized in that a penetration communicates at one end with the annular passage and at its other end is connected via a pressure isolation valve to means for monitoring and/or controlling pressure or flow within the annular passage.

The inner pipe may be a well casing and the outer pipe a barrier casing.

The penetration may be radial with respect to the bore radius of the pipe, or it may be inclined upwardly and have a portion extending in the general axial direction into another annulus at the top of the wellhead assembly.

The penetration may extend through the casing wall or run between two location on the inner surface of the wall on opposite sides of the seal for the casing defining the inner wall of the annular passageway.

Pressurizing the annulus may also be used to circulate fluids or to route material, for example drill cuttings for reinjection back into the formation, or to route returns in mud-lift systems.

The invention is now described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a schematic cross section of a conventional well assembly at a drilling stage;
Figure 2 is a schematic cross section of a subsea wellhead at seabed level showing access to an annulus via a casing wall;
Figure 3 is a modification of the subsea wellhead of Figure 2 showing two valves;
Figure 4 is a further modification of the wellhead showing penetrations to two annuli;
Figure 5 is a schematic cross section of a wellhead showing an alternative penetration route;
Figure 6 is a schematic diagram of the wellhead of Figure 5 showing a valve layout, and
Figure 7 is a schematic diagram of a well assembly at a drilling stage showing use of a penetration according to the invention in a mud lift system

Figure 1 shows the schematic layout of a well. Extending from a platform 100 is a marine riser 101 within which is a drill pipe 102. When drilling is complete the drill pipe is recovered to the surface and the casings are left hanging from the subsea wellhead. At this stage the casings will be sealed at the top but may be open at the bottom.

At mudline or seabed level a series of casing strings extend down into the formation. The more outward casing strings are suspended at the level of a subsea wellhead 10 on the seabed. Above the casing strings is a blowout preventer.

The invention generally relates to accessing one or more of the annuli defined between casing strings at the subsea wellhead level that at present are sealed for the production stage of the well. Access provided in this way may also be used at earlier stages and to provide additional functions. Access via the top of the casings is unavailable due to space considerations and the technology established for providing casing hangars and sealing. Access in the invention involves a radial or laterally extending penetration of the casing outside the annulus or more conveniently of the wellhead housing where it is in communication with the annulus. The penetration may go completely through the casing or provide a bore through to an accessible location on the inner surface of the casing that is above the hangar/seal for the casing defining the inside of the annulus.

Referring now to Figure 2, the wellhead arrangement 10 has a frame 11 installed on the seabed. The wellhead arrangement 10 has a wellhead housing 12, typically this housing may be 18¾" (approximately 476mm).

Extending down to the seabed strata from the wellhead housing 12 are four coaxial casings, termed herein as well casing 14, outer barrier pipe 15, casing 16 and conductor 17. The casings are supported on casing hangars in the generally known manner. The drawing shows hangar packoff 21 engaging with wellhead housing 12 to support well casing 14 and hangar packoff 22 engaging lower down wellhead housing 12 to support outer barrier pipe 15. A well bay insert 18 also coaxial and concentric with the wellhead housing and casings locates the wellhead and casings within the frame 11. It is usually the case that several casings are supported by the wellhead housing, it may be more than the number illustrated in the drawings.

It will be appreciated that the sizes of the casings may be any of those appropriate, for example conductor casing 17 may be 30 inches (approximately 762mm), casing 16 may then be 20 inches (508mm), barrier pipe 15 being 14 inches (356mm) and the well

casing being 103/4inches (273mm), with the wellhead housing 12 being 183/4inches (476mm).

Between adjacent casings there is an annulus of free space which is filled with a fluid such as gas, sea water, methanol or drilling mud, or other such substance as conditions demand. The annulus between well casing 14 and outer barrier pipe 15 is shown shaded and with reference 30.

It is customary for the casings to be sealed to one another both at the top, where it prevents egress of gas or other substances that might otherwise escape from the annulus, and also at the end within the seabed strata. This sealing is done at the end of the drilling process.

In the embodiment shown a radial penetration 31 is made in the wellhead housing 12, and it will be seen that at this point the annulus between casings 14 and 15 extends upwards above the seal of hangar 22 to become an annulus between the wellhead housing and the casing 14. An isolation valve 32 is provided integral with the wellhead housing 12 and this leads to an access port. The isolation valve 32 has a remotely or directly actuated valve operating arrangement outstanding from the body of the valve. These mechanisms may be of any appropriate type, for example the valve may be an hydraulic valve. The valve may be operable by a ROV.

Figure 3 shows a second embodiment in which a second isolation valve 34 is connected in series with the isolation valve 32. The second isolation valve 34 also has a remote or direct operating arrangement with provision for ROV over ride. Hard piping may lead down from the single or second isolation valve and loop round the wellhead housing 12 to a connection point. Various monitoring/control features relating to the well output may be connected to the connection point.

As well as monitoring conditions in the annulus, excess pressure in the annulus can be relieved via the isolation valve or valves, or the annulus between the casings 14 and 15 can be pressurised by pumping a fluid medium (e.g. methanol) through the valve or valves, and via the penetration 31, into the annulus. Pressurisation of the annulus

outside the well casing 14 may allow higher pressures to be contained within that casing. The invention provides ability to top up pressure to compensate for outward leakage, change of state or pressure reduction due to temperature variation, or to reduce pressure in the corresponding converse circumstances.

In order to position the penetration and isolation valves with respect to the external layout it may be necessary to provide an alignment mechanism. This is particularly the case if the connections use rigid pipes. In the embodiments shown orientation between the template 11 and the conductor housing 20 and also between the conductor housing 20 and the wellhead housing 12 is achieved by alignment keys.

Alternatively a flexible conduit may lead off from the isolation valve 32 (or 34) to pressure monitoring/control features elsewhere on the wellhead arrangement 10 or on associated equipment. The wellhead housing 12 is installed complete with annulus monitoring valve and flexible hose. A welded connection attaches the casing 16 to the bottom of the wellhead. Only rough orientation is required.

It is possible for pressure in different ones of the annuli between casings to be monitored or adjusted, or for more than one annulus, possibly even all, to be so monitored or controlled. Figure 4 shows an arrangement where the annulus between casings 15 and 16 is monitored and/or adjusted via a second penetration 41. At the level of penetration 41 through the wellhead housing 12, the wellhead housing forms an extension of the annulus between casings 15 and 16, it being above the suspension hangar for casing 16, but it is also below the seal for casing 15 and so isolated from the more inward annulus between casings 14 and 15. It will be appreciated that as the progressively more outward casing strings are hung at progressively lower levels, a penetration to access them will also be at a lower level, intermediate the casing hangars of the respective casings that form the annulus.

When there are a plurality of penetrations to different annuli they do not all have to be provided with the same facilities. For instance it may be required only to monitor one or more while others may need to have pressure controls. The provision of a penetration may in some cases be used to pressurise only at the completion/sealing stage with lesser

monitoring only equipment being installed subsequently.

In the embodiments described above the penetration is radial though it could be inclined and an alignment framework is required. Also additional connections between the subsea tree and the alignment framework are required. In an alternative embodiment shown in Figures 5 and 6 the additional connections can be avoided by extending the penetration passageway to a void that is created between an isolation sleeve (reference 40) and the wellhead housing.

As in previous embodiments, the wellhead assembly 10 has a wellhead housing 12, well casing 14 and outer barrier pipe 15.

As can be seen in Figure 5, as the wellhead body 12 extends upwardly beyond the casing hangar 22 there is an upper annulus defined between the wellhead body 12 and an isolation sleeve 40. In this embodiment a passage is created through the wellhead body from the annulus between casings 14 and 15 and into the upper annulus. This enables the monitoring and pressure adjustment mechanism to be located higher up and avoid extra connections to the tree.

In Figure 5, the first part of the passageway from the annulus between casings 14 and 15 has an opening in the same location on the inside of the wellhead housing as previous embodiments. This time bore 31 is upwardly inclined and communicates with an access port additionally provided on the wellhead housing. A valve 43, such as a small bore gate valve is provided within bore 31 to isolate the pressure of the annulus. The port and this location for the valve are option. Penetration through the wall of the wellhead is not needed but blocking a through bore with a port may be a more convenient way of providing the passageway.

The passageway then continues through further communicating bores 44, 45 and 46 to the upper annulus and then via bore 48 to valves and connections at the top of the wellhead assembly. The arrangement shown is a convenient way to drill the bores, however all that is required is to provide a looped passage from the inner surface of the

wellhead housing below packoff 21 to the inner surface of the wellhead housing above packoff 21. Thus the configuration, number and inclination of the bores may vary.

Figure 6 shows schematically the bores and valves of the assembly. Hydrocarbon fluids emerge from the well bore to an outlet 50 via a primary master valve 51 and primary wing valve 52. When isolation valve 43 is open the monitoring and control of the annulus pressure is via valve 53 and, optionally, other valves shown generally at 54.

Valves controlling full flow of hydrocarbon fluids and access to the annulus between casings 14 and 15 can be applied both to Side Valve Trees (also known as Horizontal Trees or Spool Trees) and conventional trees.

The specific example of the invention described above with reference to Figures 5 and 6 has the advantages that it eliminates the use of additional connections and isolation valves between the wellhead system and the subsea tree system. It does not add any extra operations to the conventional running/installation procedures for the tree or wellhead as it is usual to have test ports in this annulus, for example to test the connection between the Subsea Xmas Tree and the Subsea wellhead. Thus this communication will in this embodiment additionally have the application of monitoring the annulus, once the closure/isolation mechanism is left open in the wellhead.

The embodiment of Figures 5 and 6 may also be used in combination with lower level penetrations to one or more annulus at lower levels as described in respect of the embodiment of Figure 4. Likewise a looped passageway from between other pairs of packoffs to above packoff 21 may also be provided. Isolating valves and onward separate routing would be required if more than one annulus is connected to the annulus between the wellhead housing and isolation sleeve.

It will be appreciated that the embodiments described are all situated below the Blowout preventor and therefore do not interfere with the construction of that part of the assembly.

The invention has been described so far generally within the context of coaxial casings that have, or will be, sealed at their top and at the base of the more outward casing so as to form an enclosed, sealed annulus. While it is most probable that top seals will always be in place, there need not always be a lower seal. This then offers the possibility of monitoring pressure that is in communication with seabed strata or of applying pressure or introducing fluid or material to the formation via the open end of the annulus. The open lower end of the casing may have modified structure or openings for specific purposes.

Figure 7 shows a so called `mud lift` system employing a modification of the invention used during drilling.

Mud lift systems have been proposed for deep drilling where the weight of mud in the marine riser as shown in Figure 1 is too great to be supported by the formation. To overcome this there have been proposals to seal the marine riser at the subsea wellhead level and only have seawater in the riser above that level. It is then proposed to pump the mud via a mud return to the surface. However such systems have not yet evolved due to the complexity of routing the mud from the riser. Proposals for this routing have been located within the blowout preventer (BOP) which is both complex and requires redesign of the BOP.

The present invention proposes providing a penetration 31 as previously described and connecting the penetration to the mud lift system. In a further modification (not shown), a penetration may be provided to route the mud into a casing outside the marine riser, or even back into the marine riser if the load is supported at the level of the seal.

The arrangements described in respect of Figure 7 may also be used to transfer material in the reverse direction. For example after drilling, drill cuttings may be reinjected back into the formation. This reinjection may alternatively be performed between other casings, with open lower ends providing access to the formation.

After use for mud lift and/or reinjection as the case may be, the same penetration may be used at the production stage for monitoring, control or other functions.

A further embodiment of the invention may establish multiple penetrations into an annulus so as to provide a flow path. Such a flow path may be used to drive a pump located in the annulus. Adjacent annuli may be interconnected by a penetration in their common casing (at a lower level) and then penetrations as described above to each of the annuli used as respective inward and outward flow paths.

Interconnection of casing annuli via a looped penetration in the wellhead housing is also possible in a manner similar to the connection shown between the casing 14 and 15 annulus and the upper annulus in Figure 5.

CLAIMS

1. A wellhead housing assembly for a subsea wellhead, the assembly comprising a wellhead housing that is adapted to receive a plurality of casing strings therewithin with an annular passage defined between respective adjacent casing strings,

and in which the wall of the wellhead housing has a penetration with a first opening on its inner surface in a location that will communicate with one annular passageway formed by a pair of adjacent casing strings, the penetration extending to a second opening on a surface portion of the wellhead housing wall that will not be in communication with any annular passageway between casing strings.

2. A wellhead housing assembly according to claim 1 in which the second opening of the penetration is on the exterior of the wellhead housing.

3. A wellhead housing assembly according to claim 2 in which the penetration extends through the wellhead housing wall substantially radially.

4. A casing string assembly according to claim 2 in which the penetration extends through the wellhead housing wall at an angle inclined longitudinally from radial.

5. A casing string assembly according to any preceding claim in which the penetration is below a location for a casing hangar seal for the casing string defining the inner wall of the annular passageway.

6. A wellhead housing assembly according to any preceding claim 1 in which a plurality of penetrations are provided each with a first opening located to communicate with an annulus defined by respective different pairs of adjacent casing strings.

7. A wellhead housing assembly according to claim 1 in which the second opening of the penetration is on the interior of the wellhead housing above a location for a casing hangar seal for the casing string defining the inner wall of the annular passageway

8. A wellhead housing assembly according to claim 7 in which second end of the penetration communicates with a location where the wellhead housing defines an annulus with an isolation sleeve.

9. A wellhead housing assembly according to claim 7 or claim 8 in which the penetration comprises a series of bores including one bore extending in the axial direction.

10 A wellhead housing assembly according to any preceding claim further comprising an isolation valve in communication with the passageway.

11. A wellhead housing assembly according to claim 10 in which the isolation valve is integral with the wellhead housing.

12. A pressure monitoring/control system for a subsea wellhead arrangement including a wellhead housing assembly according to any preceding claim and means for monitoring and/or controlling pressure or flow within the annular passage.

13. A subsea wellhead arrangement having a plurality of casing strings disposed coaxially with respective adjacent casing strings defining an annular passage therebetween, and in which a respectively outward one of adjacent casings strings has a passageway in its wall with a first opening communicating with the annulus and a second opening connecting to apparatus for monitoring or controlling pressure or flow within the annular passage.

14. A subsea wellhead arrangement according to claim 12 in which the respectively outward one of the casings defining the annular passageway is open at its lower end and material is routed via the open end and passageway.

15. A subsea wellhead arrangement according to claim 14 in which the material is drill cuttings routed for reinjection to the formation.

16. A subsea wellhead arrangement according to claim 14 in which the material is

mud in a mud-lift system.

17. A subsea wellhead arrangement according to claim 13 in which flow in the annulus is used to drive a pump.

18. A subsea wellhead arrangement according to claim 12 or claim 13 in which there are a adjacent annular passageways defined between three concentrically disposed casings and an additional penetration to connect the annuli is made in the common casing.

19. A subsea wellhead arrangement according to any preceding claim in which a bore in the wellhead housing interconnects two annular passageways between casing strings.

20. A subsea wellhead arrangement according to claim 18 in which the bore has a first opening between the seals for a first pair of casing strings and a second opening between seals for a second pair of casing strings.

21. A pressure monitoring/control system for a subsea wellhead arrangement including an inner pipe surrounded by an outer pipe and defining an annular passage therewith, the inner and outer pipes being adapted to withstand internal and external pressure and the annular passage being filled with fluid to prevent compression,

characterized in that a penetration communicates at one end with the annular passage and at its other end is connected via a pressure isolation valve to means for monitoring and/or controlling pressure or flow within the annular passage.

22. A system according to claim 21 in which the penetration is in the wellhead housing with said one end at a level communicating with the annulus.

23. A system according to claim 21 in which the end of the penetration communicating with the annulus is below a casing seal for the inner pipe and above a casing seal for the outer pipe.

24. A system according to claim 21 in which the inner pipe is a well casing and the outer pipe is a barrier casing and the means for monitoring connects to a component at the subsea wellhead.

25. A system as claimed in claim 21 in which the penetration is radial with respect to the well bore.

26. A system as claimed in any of claims 21 to 25, in which a second isolation valve is connected in series with said pressure isolation valve.

27. A system as claimed in any one of claims 21 to 26, in which the isolation valve or valves are operable hydraulically, with provision for ROV override.

28. A system as claimed in any one of claims 21 to 27, in which there is a rigid connection between the isolation valve and the monitoring/control feature.

29. A system as claimed in claim 28, in which there is an alignment key between an outer housing and a system support structure to ensure aligned engagement of the rigid connection and the support structure.

30. A system as claimed in any one of claims 21 to 27, in which there is a flexible connection between the isolation valve and the monitoring/control feature.

31. A system as claimed in any one of claims 21 to 30, in combination with means to control/monitor fluid pressure within the annulus between the well casing and the outer barrier pipe, whereby to increase the allowable pressure within the well casing.

32. A system as claimed in any one of claims 21 to 31, in which there is another pipe surrounding the outer barrier pipe, so forming a second annulus surrounding the annulus aforesaid, and in which there is a second penetration leading to another isolation valve by which the pressure in the second annulus may be monitored/controlled.

33. A pressure monitoring/control system according to any of claims 21 to 32 in which the isolation valve is integral with the wellhead housing.

34. A pressure monitoring/control system according to claim 21 in which the penetration has a portion that extends axially within the housing to a further annulus near to the top of the wellhead arrangement.

35. A system as claimed in claim 21 in which part of the penetration in the wellhead housing is directed radially upward and outward with respect to the well bore.

36. A system as claimed in claim 34 or claim 35, in which a second isolation valve is connected to an outflow from the further annulus in series with the isolation valve aforesaid.

37. A system as claimed in any of claims 21 to 36 in which the end of the penetration communicating with the annular passage is formed between the casing hangers for the well casing and the next outer casing.

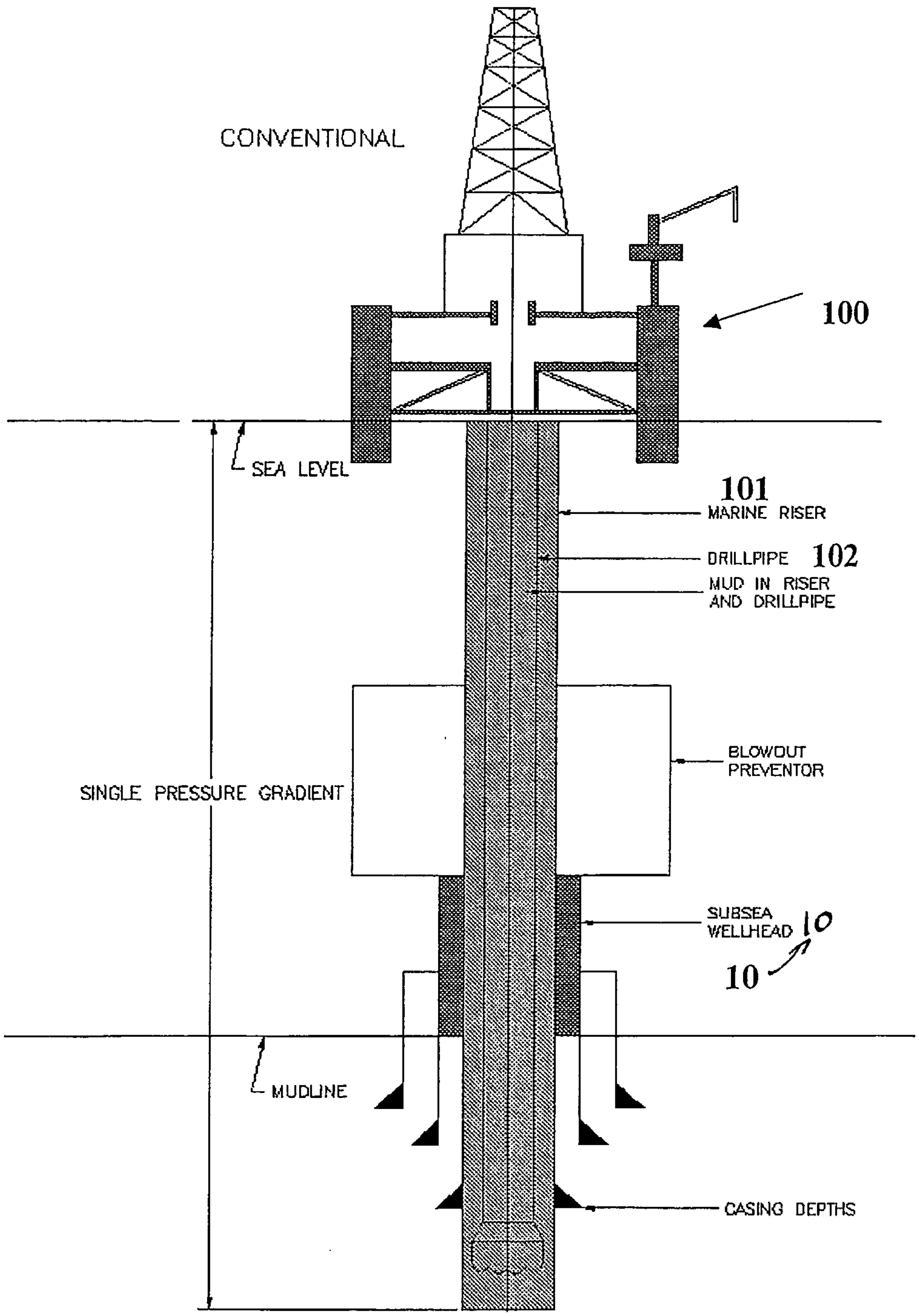
38. A system as claimed in claim 34 in which the isolation valve in the wellhead housing is a small bore gate valve with metal to metal sealing.

39. A system as claimed in claim 34 in which the further annulus is between a tree isolation sleeve and a connector body.

40. A system as claimed in claim 39, in which a port is formed in the connector body and the outlet includes the second isolation valve.

41. A system as claimed in any of claims 21 to 40, in which the isolation valve or valves are operable hydraulically.

42. A system as claimed in any of claims 21 to 41, in combination with means to control/monitor fluid pressure within the annulus between the well casing and the outer barrier pipe, whereby to increase the allowable pressure within the well casing.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SUBSEA WELLHEAD 10
10
MUDLINE
CASING DEPTHS

Figure 1

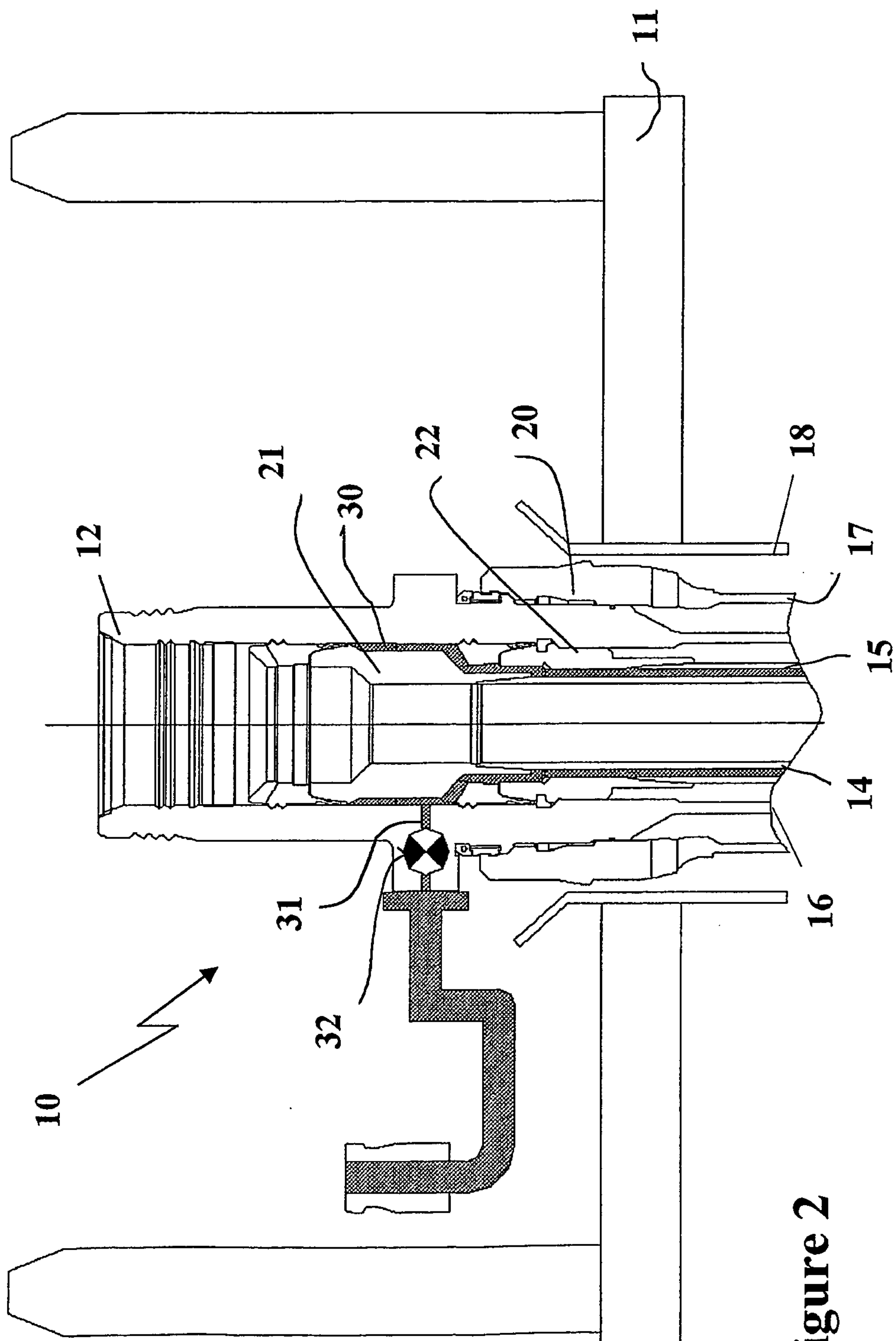


Figure 2

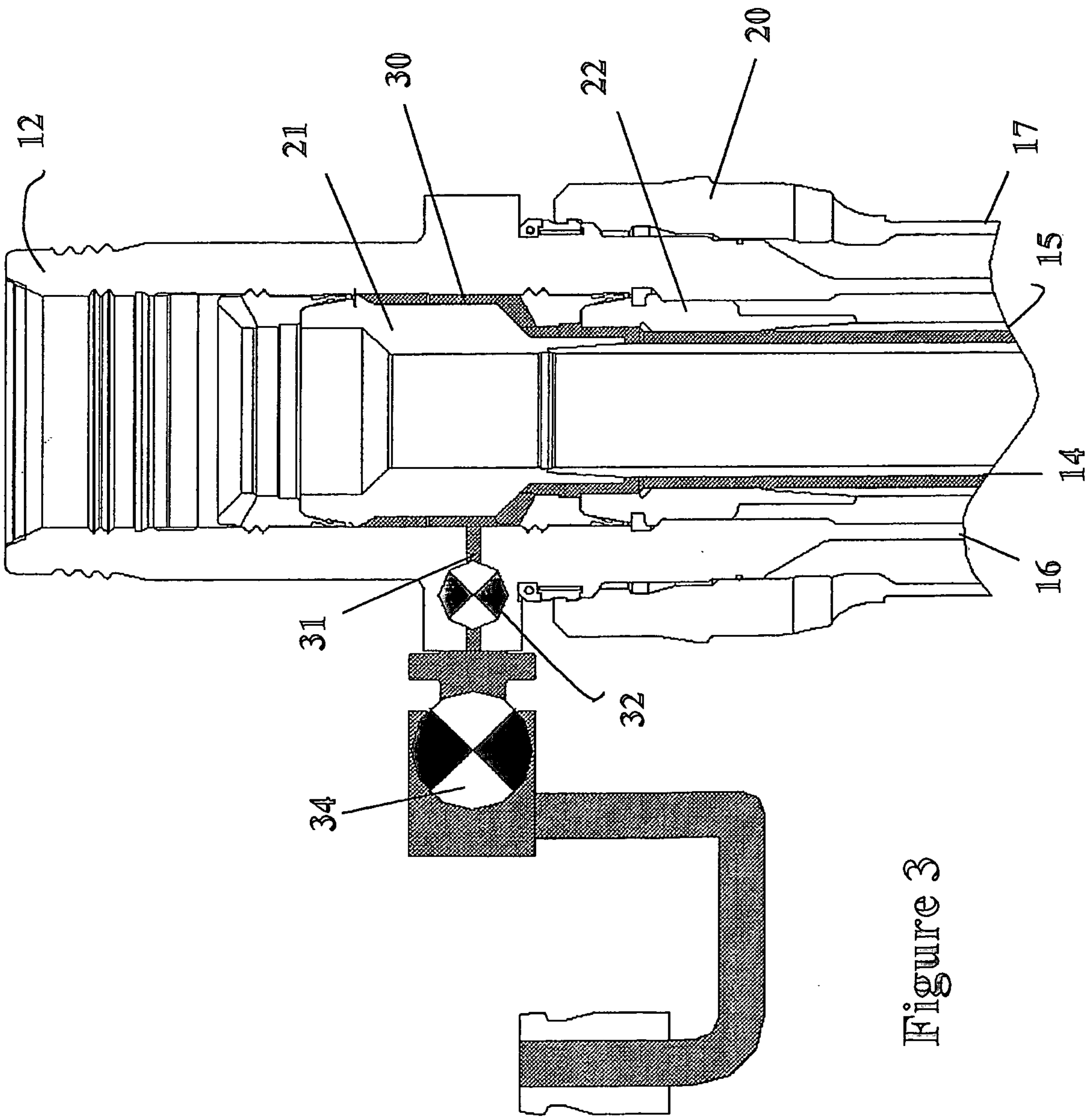


Figure 3

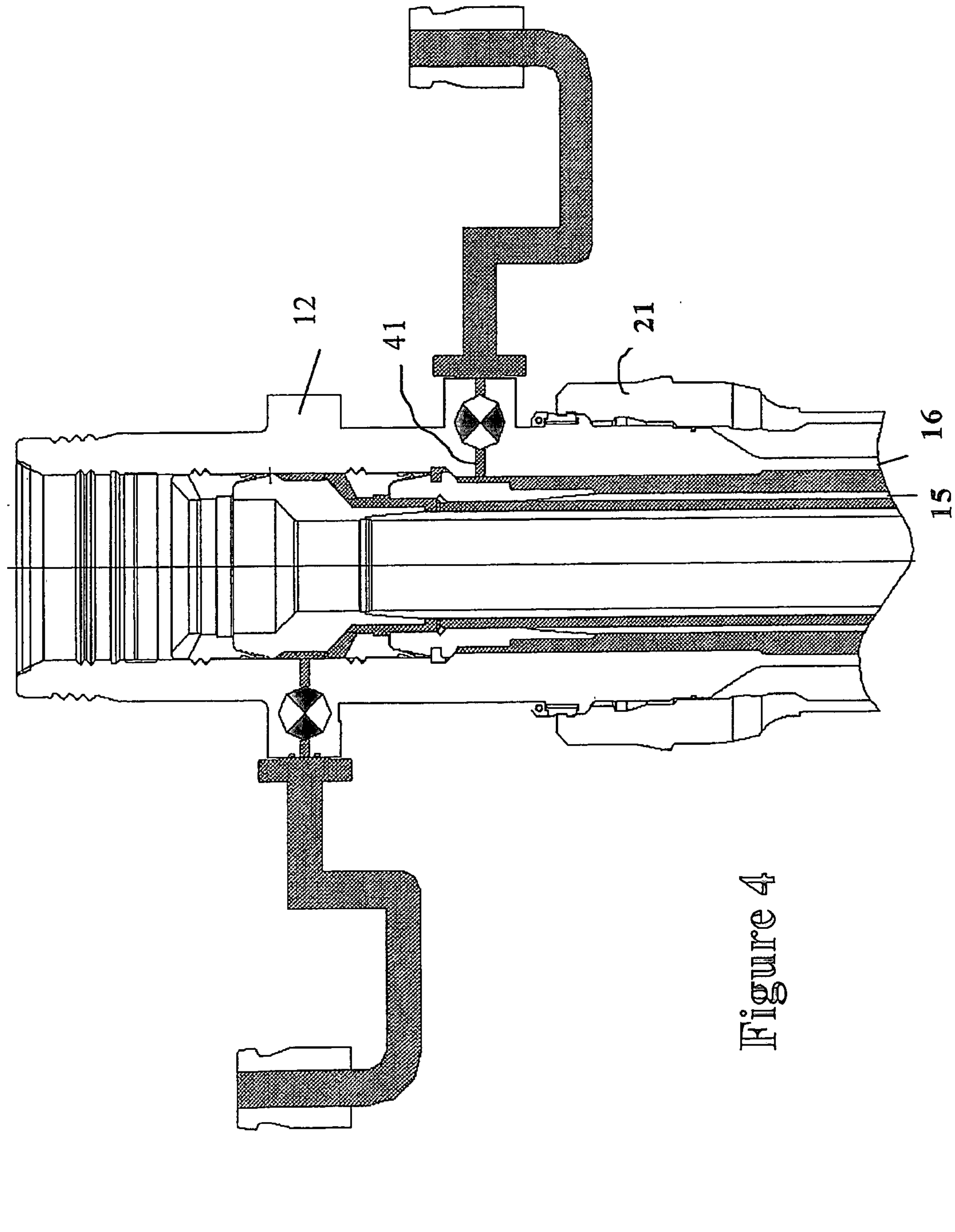


Figure 4

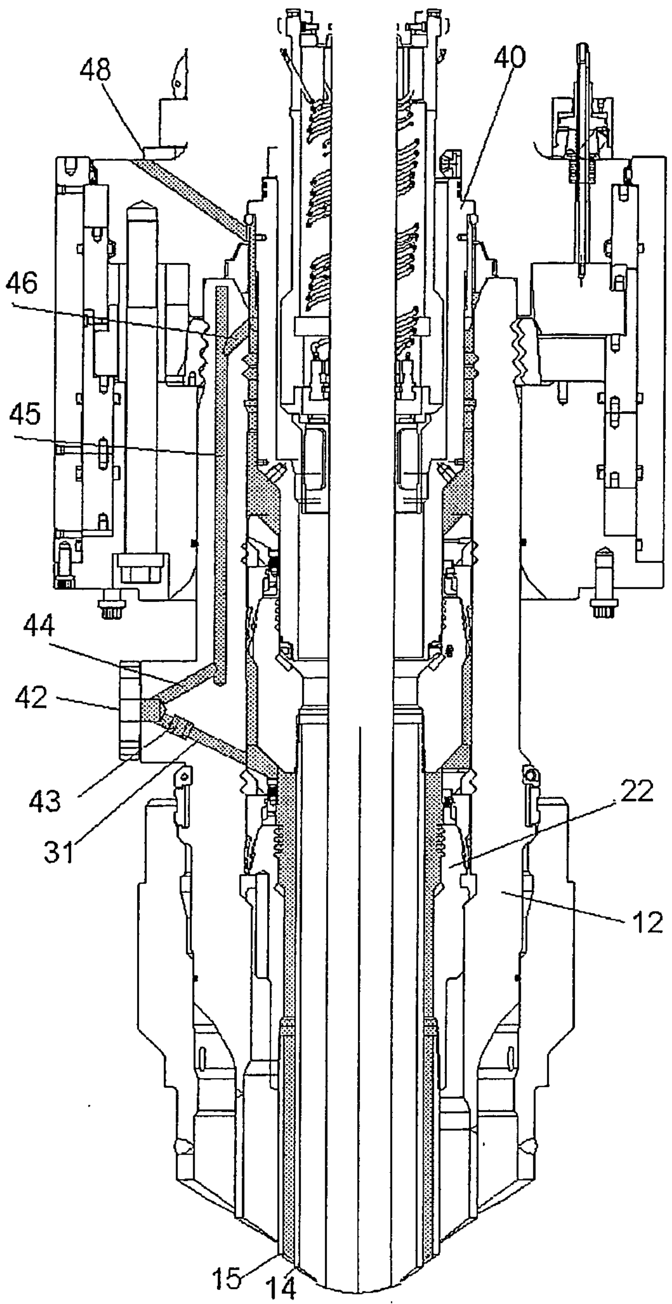


Figure 5

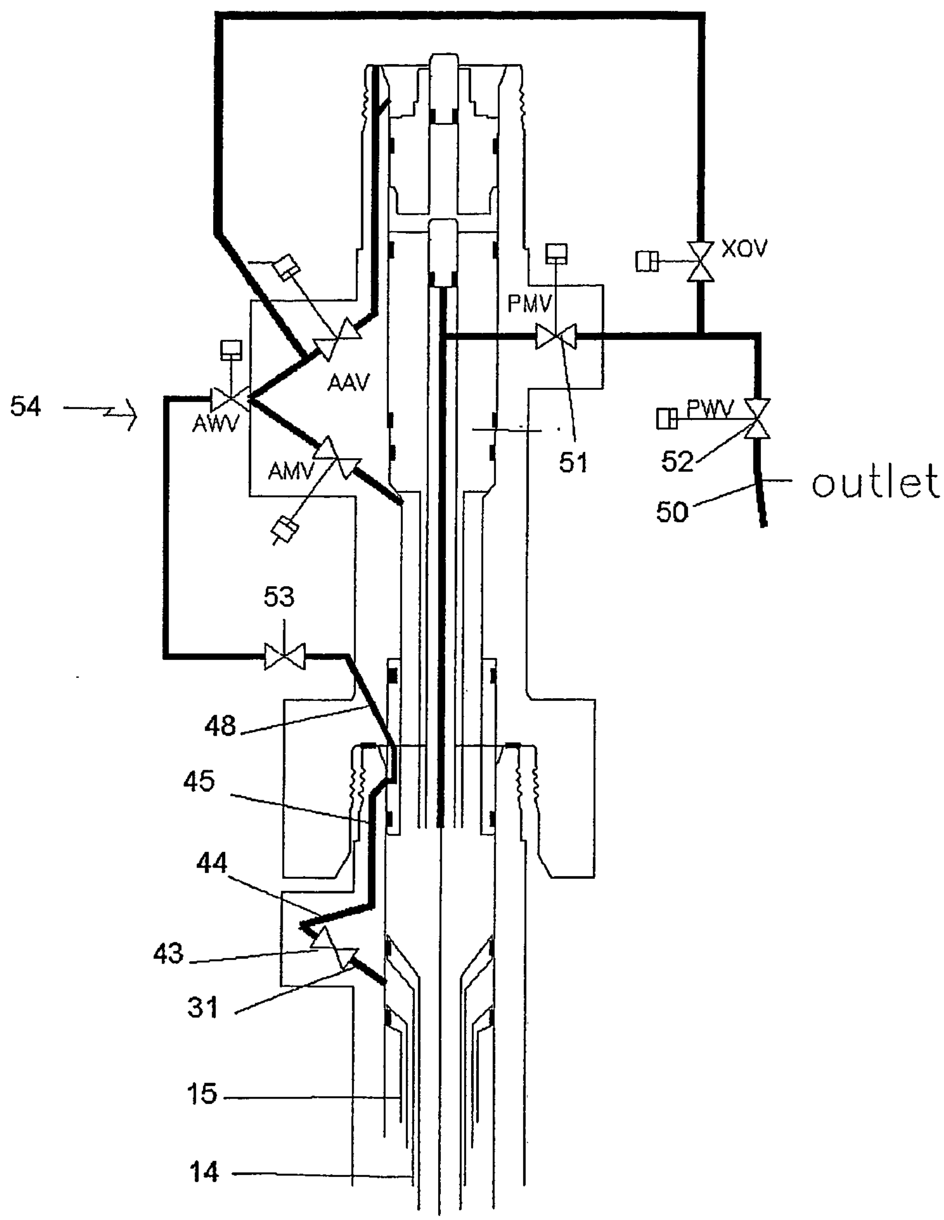
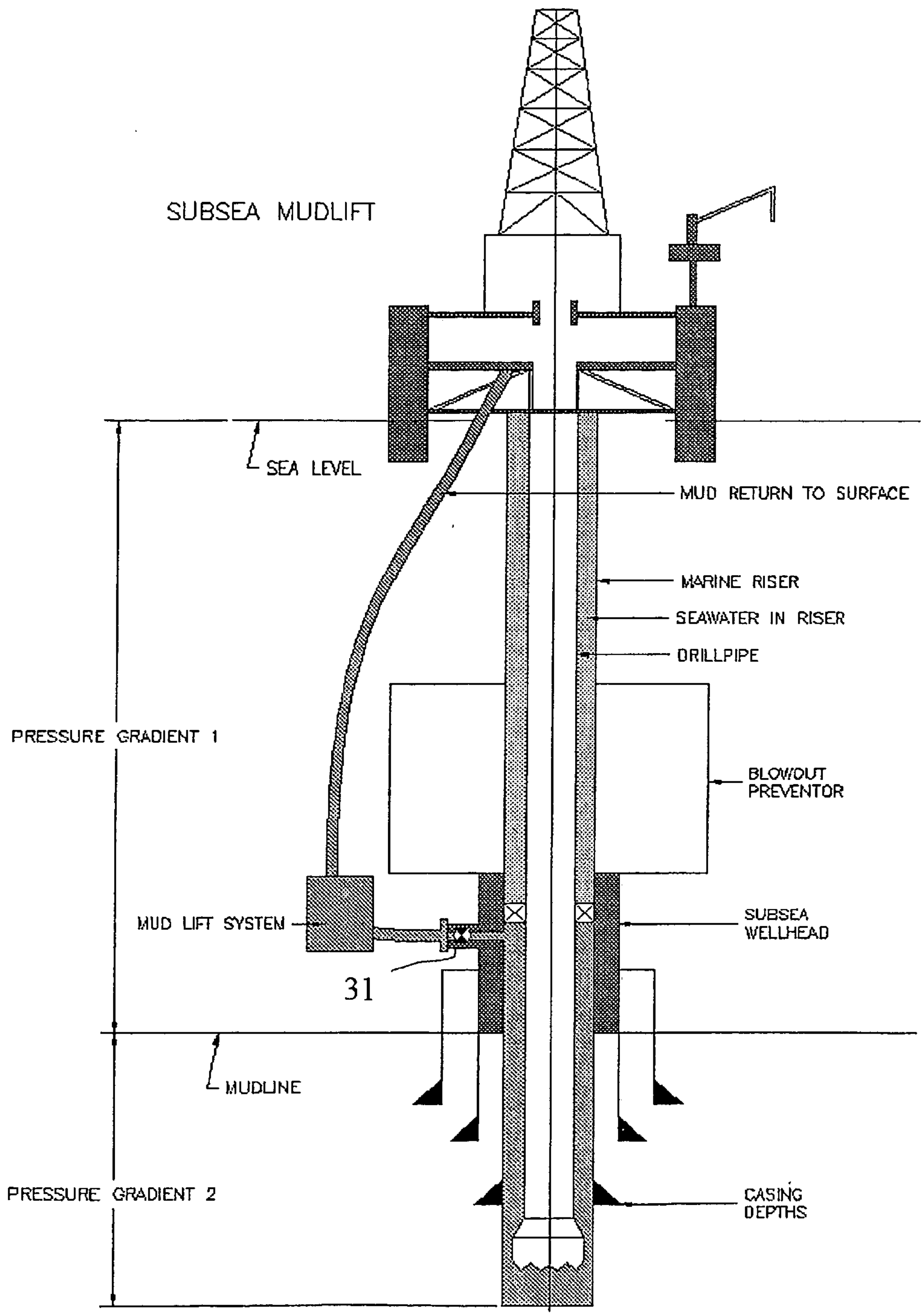


Figure 6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MARINE RISER
SEAWATER IN RISER
DRILLPIPE
PRESSURE GRADIENT 1
BLOWOUT PREVENTOR
MUD LIFT SYSTEM
SUBSEA WELLHEAD
31
MUDLINE
PRESSURE GRADIENT 2
CASING DEPTHS

Figure 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/03809

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B33/035 E21B33/043 E21B33/047

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 326 430 A (PLEXUS OCEAN SYST LTD) 23 December 1998 (1998-12-23) page 2, line 30 -page 4, line 35; figure 1	1-6, 12-14, 18,20
Y	figure 5	7-11
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[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
3 December 2002	20/12/2002
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Authorized officer Morrish, S

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/03809

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